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The Sacramento–San Joaquin River Delta (Delta) and Suisun Marsh are critically important to the state and the nation for a wide variety of environmental and economic services (benefits derived from the area). Approximately 1,115 miles of levees in the Delta and 230 miles of levees in Suisun Marsh define the configuration of the waterways and landforms of the area. Most of these levees hold back water (i.e., prevent water from flowing onto the adjacent land) for 365 days per year, not just during floods. Over the years, many state and federal agencies and stakeholders have voiced concern over the condition of the Delta and Suisun Marsh levees and the consequences should they fail.

DRMS progress can be followed on the Delta Risk Management Strategy web portal:

http://www.drms.water.ca.gov/

1.1 PURPOSE

The overall purpose of the Delta Risk Management Strategy (DRMS) project is to assess the performance of Delta and Suisun Marsh levees (under various stressors and hazards) and the potential economic, environmental, and public health and safety consequences of levee failures to the Delta region and to California as a whole (Phase 1) and to develop and evaluate risk reduction strategies (Phase 2). This report presents the methodology and results for Phase 2 of the project.

The Record of Decision for the CALFED Bay-Delta Program (CALFED 2000) called for a DRMS to be completed by 2001. The California Department of Water Resources (DWR), the California Department of Fish and Game, and the U.S. Army Corps of Engineers (USACE) initiated DRMS in response to Assembly Bill (AB) 1200.

1.1.1 Assembly Bill 1200

AB 1200 (Laird, Chaptered October 2005) required DWR to evaluate the potential impacts on water supplies derived from the Delta resulting from a variety of risks.

The bill amends Section 139.2 of the Water Code to read, "The department shall evaluate the potential impacts on water supplies derived from the Delta based on 50-, 100-, and 200-year projections for each of the following possible impacts on the Delta:

1. Subsidence
2. Earthquakes
3. Floods

Delta Facts

- About 1,115 miles of levees protect 700,000 acres of lowland in the Sacramento–San Joaquin River Delta. In Suisun Marsh, approximately 230 miles of levees protect over 50,000 acres of marsh land.
- Only about a third of the Delta levees (385 miles) are project levees, which were part of an authorized federal flood control project for the Sacramento and San Joaquin River systems. However, the vast majority of Delta levees, over 730 miles, and about 210 miles of Suisun Marsh levees are nonproject (local) levees.
- Local levees have been constructed, enlarged, and maintained over the last 130 years by local reclamation districts. In general, the levee work by these districts was financed by the owners of the lands protected by the levees. Over about the last 30 years, the State of California has provided supplemental financing for levee maintenance and emergency response.
- Flooding from levee failures can influence the following services:
  - Land use (agriculture, urban, and conservation areas)
  - Flood management
  - Ecosystem
  - Water supply
  - Water quality management
  - Transportation
  - Utilities
  - Recreation and tourism
  - Local and state economics

4. Changes in precipitation, temperature, and ocean levels
5. A combination of the impacts specified in paragraphs (1) to (4) inclusive"

Also, Section 139.4 was amended to read: (a) The department and the Department of Fish and Game shall determine the principal options for the Delta. (b) The department shall evaluate and comparatively rate each option determined in subdivision (a) for its ability to do the following:

1. Prevent the disruption of water supplies derived from the Delta.
2. Improve the quality of drinking water supplies derived from the Delta.
3. Reduce the amount of salts contained in Delta water and delivered to, and often retained in, our agricultural areas.
4. Maintain Delta water quality for Delta users.
5. Assist in preserving Delta lands.
6. Protect water rights of the "area of origin" and protect the environments of the Sacramento–San Joaquin River systems.
7. Protect highways, utility facilities, and other infrastructure located within the Delta.
8. Preserve, protect, and improve Delta levees.…"

DRMS was developed to address the provisions of Sections 139.2 and 139.4 of AB 1200.

1.1.2 Goals and Objectives

The sponsors and the project Steering Committee (see Sections 1.4.1 and 1.4.2 for more details) developed the following objectives for the DRMS work in accordance with the provisions of AB 1200:

1. Evaluate the risk[1] and consequences to the state (e.g., water export disruption and economic impact) and the Delta (e.g., levees, infrastructure, and ecosystem) associated with the failure of Delta levees and other assets considering their exposure to all hazards (seismic, flood, subsidence, seepage, sea-level rise) under present as well as foreseeable future conditions. The evaluation shall assess the total risk and disaggregate the risk for the individual islands.
2. Propose risk criteria for consideration of alternative risk management strategies and for use in management of the Delta and the implementation of risk-informed policies.
3. Develop a DRMS, including a prioritized list of actions to reduce and manage the risks or consequences associated with Delta levee failures.

Specifically, the objective of DRMS Phase 2 is to build on the results developed in DRMS Phase 1. The Phase 2 work is focused on developing improvement strategies to reduce the risk estimated in Phase 1. Phase 1 has uncovered areas of vulnerabilities for the flood control (levee) system when it is subjected to the hazards and stressors considered. The vulnerabilities of the levee system were quantified in terms of likelihood of failure by regions in time and under various loading conditions. The risk analysis in Phase 1 also looked at the consequences

[1] See Section 3 of the DRMS Phase 1 Risk Analysis Report (URS/JBA 2008h) for a definition and discussion of risk.

(impacts) to the ecosystem, the local and state economy, local infrastructure, water quality and water export reliability, and the population at risk in accordance with the stated goals of AB 1200.

Armed with the knowledge gained from the Phase 1 Risk Analysis Report (URS/JBA 2008h), the DRMS consulting team developed improvement solutions (strategies) in Phase 2 that increase the reliability of those systems that present the highest risks and quantified the risk reduction to the various resources and assets of the Delta and Suisun Marsh under the alternative improvement solutions. To do so, the improvement strategies are developed in sufficient detail to allow the development and implementation of the risk model and to quantify the risk associated with the alternative improvement solutions. Those improvements require enough engineering development to ensure that they are feasible and constructible and that they can be quantified in sufficient detail to allow development of a feasibility-level construction cost estimate.

Two sets of improvements are defined: *building blocks* and *scenarios.* The building blocks are defined as individual improvements that cannot be further divided into sub-components and still maintain their functionality as built projects. Thus, building blocks could be projects such as improved levees, a through-Delta conveyance, raised highways, increased subvention funding, and emergency planning and response preparedness. Each of these projects is referred to as a building block. Building blocks generally have a single to a limited number of benefits. Scenarios, by contrast, are defined as ensembles or combinations of building blocks. The scenarios aim to achieve multiple risk reduction objectives or benefits to the various assets and resources in the Delta and Suisun Marsh.

The products of the Phase 2 work will consist of a set of risk reduction evaluation tools that will allow for risk-based Delta conceptualizing and decision-making.

1.2 RISK ANALYSIS SUMMARY

The Phase 1 work involves the development and implementation of a risk analysis model to evaluate the risks from various stressing events to the Delta and Suisun Marsh levees. The DRMS Phase 1 Risk Analysis Report (URS/JBA 2008h) provides a framework for evaluating major threats, or hazards, to the Delta levee system and the consequences of levee failures. In Section 13 of the Risk Analysis Report, risk is evaluated under 2005 base year conditions under the assumption that existing management practices (policies, funding, maintenance) continue (this assumption is referred to as “business as usual”). Section 14 of the Risk Analysis Report evaluates how the risks identified for the 2005 base year evolve and compound into the future.

1.3 PHASE 2 EVALUATION

The focus of the Phase 2 effort is to evaluate alternatives to reduce the risk to the Delta and the state from adverse consequences. In the early stages of the process of identifying alternatives, the DRMS consulting team reviewed the results of prior studies of the Delta and held various levels of discussion and interaction with the DRMS project sponsors and Steering Committee (see Sections 1.4.1 and 1.4.2, respectively, for more information). At the same time, the project sponsors, Steering Committee, and consulting team interacted with a number of parallel activities that were under way. These activities, which included the Delta Regional Ecosystem Restoration

Implementation Plan, the Governor's Delta Vision process, and the Bay-Delta Conservation Plan (BDCP), were investigating proposed solutions for managing the Delta in the future.

In light of these activities—particularly, the Delta Vision process—two concepts became apparent. First, the DRMS Phase 2 evaluation should be conducted in a manner that does not produce just "another" proposal for managing the Delta in the future; rather, DRMS should provide information that can support these efforts. Second, the complexity of the issues in the Delta and the time available to undertake the Phase 2 effort necessarily require a second iteration of the process of identifying and evaluating alternatives. This next step will take advantage of the knowledge gained from the first iteration, the results of the initial Phase 2 analysis, and the direction and findings of other ongoing efforts, such as the Delta Vision process as it closes in on the recommendations it will make to the Governor and the state legislature.

The result of this process was a decision to identify alternative building blocks and scenarios which in themselves are not specific proposals for managing the Delta in the future, but instead are a set of options that cover a range of alternatives. The evaluation of these options can provide insight into where risk-reduction benefits exist. To define the building blocks and scenarios to be evaluated in Phase 2, DWR and the DRMS consulting team identified an initial list that was provided to the project Steering Committee. After a series of meetings with the Steering Committee, DWR and the consulting team selected the final set of building blocks and scenarios to be evaluated.

1.4 PROJECT TEAM

1.4.1 Project Sponsors

The DRMS project has been funded entirely by DWR. DWR, the California Department of Fish and Game, and the U.S. Army Corps of Engineers serve as the project sponsors. The sponsors are assisted by a Steering Committee, which consists of Technical Advisors and Delta stakeholders.

1.4.2 Steering Committee

Steering Committee members are policy advisors who represent the interests of the Delta and the interests of those outside the Delta who rely on the Delta infrastructure. The role of the Steering Committee members is to ensure proper coordination among agencies, the public, and the DRMS consulting team. The members are expected to speak with authority on the positions of their constituencies and have access to policymakers within their organizations, when needed. The Steering Committee provides policy advice to the project sponsors and the DRMS consulting team.

1.4.3 Technical Advisory Committee

The Technical Advisory Committee, whose members are de facto members of the Steering Committee, has the same roles and responsibilities as those just described for the Steering Committee. Also, the Technical Advisory Committee members are technical subject matter experts and serve, at the direction of the project sponsors, as independent reviewers of the DRMS project work.

The Technical Advisory Committee reviews both the interim and the final work products of the DRMS consulting team. The committee provides written comments and advice on the appropriateness of the methods used to develop the technical products. In its role as an independent reviewer, the committee does not produce or generate work on the DRMS project.

1.4.4 DRMS Consulting Team

The project sponsors selected the consulting team of URS Corporation (URS) and Jack R. Benjamin & Associates, Inc. (JBA), to perform the DRMS work. The team was given authorization to proceed with work in March 2006. The work schedule calls for the Phase 1 work to be completed in December 2008 and the Phase 2 work to be completed in January 2009.

The consulting team includes 23 firms located in the Sacramento/Bay Area/Stockton region. These local firms and independent consultants bring extensive local experience with the Delta in their respective fields of specialization. The firms and the services they provide are described below. Figure 1-1 shows the program functional organization. (Tables and figures are located at the end of each section.)

URS Corporation: Risk Analysis, Geotechnical Engineering, Seismic Hazard and Earthquake Engineering, Hydraulics/Hydrology, Flood Hazard, Water Quality, Vegetation and Habitat Analysis, Infrastructure, GIS

Jack R. Benjamin & Associates, Inc.: Risk Analysis and Modeling, Water Management

Resource Management Associates: Delta Hydrodynamic Modeling

MBK Engineers: Reservoir Operation and Water Management

Bay Modeling-Hydrodynamics: 3-D Hydrodynamic Modeling, Sea Level Rise Simulation

Watercourse Engineering, Inc.: Hydrodynamics and Water Management

Geomatrix Consultants, Inc.: Seismic Hazard, Earthquake Engineering, Geotechnical Engineering

Kleinfelder, Inc.: Geotechnical Engineering

Hultgren & Tillis Engineers: Geotechnical Engineering

HydroFocus, Inc.: Subsidence

WLA Consulting, Inc.: Seismic Geology, Fault Characterization

Pacific Engineering & Analysis: Ground Motions and Site Response

Phillip Williams Associates: Geomorphology, Wind-Wave Modeling

Moffatt & Nichol Engineers: Emergency Response, Erosion

Economic Insight: Economic Analysis

RM Econ: Economic Analysis

Western Resource Economics: Economic Analysis

M-Cubed: Economic Analysis

Redars Group: Traffic Impact Analysis

Hanson Environmental, Inc.: Environmental and Ecosystem Impact Analysis

Stevens Consulting: Environmental and Ecosystem Impact Analysis

Science Applications International Corporation: Terrestrial Habitat
Jones & Stokes: Water Quality, Environmental Impacts

1.4.5 Risk Resources Group

The DRMS consulting team also includes a Risk Resources Group, which was formed to advise on specialized risk modeling issues in the various topical groups. These individuals served primarily as individual consultants on an as-needed basis. The Risk Resources Group consists of the following experts:

C. Allin Cornell, PhD (deceased) (Stanford University): Risk Analysis, Uncertainty, Seismic Hazard
Gregory Baecher, PhD (University of Maryland): Probability, Reliability, Geotechnical
Des Hartford, PhD: Policy and Risk Analysis, Geotech, Flood
Ralph Keeny, PhD (Purdue University): Decision Analysis, Public Policy
James H. Cowan, Jr., PhD (Louisiana State University): Aquatic Fishery
Mark T. Stacey, PhD (University of California, Berkeley): Fluid Mechanics/Hydrology
Michael W. Hanemann, PhD (University of California, Berkeley): Economics
Stuart W. Siegle, PhD: Wetland, Estuarine and Riparian Ecosystem
Mark A. Snyder, PhD (University of California, Berkeley, Santa Cruz): Climate Change
Jeff Hart, PhD: Delta Botanicals and Restoration
Chris Kjeldsen, PhD: Delta Botanicals and Restoration

1.5 RELATIONSHIP TO OTHER INITIATIVES

1.5.1 Delta Vision

The role of the Delta Vision initiative (Governor Schwarzenegger's Executive Order S-17-06) is to identify a strategy for managing the Delta as a sustainable system for all environmental and economic services that the Delta provides. The Delta Vision initiative is a significant public process designed to find substantial agreement on recommendations among elected officials, government agencies, stakeholders, subject matter experts, and affected California communities on:

1. The multiple uses, resources, and ecosystem in the Delta that can be sustained over the next 100 years or more
2. The array of public policies and resource management strategies needed to move toward this strategic vision for the Delta
3. A near-term (next 25–50 years) contingency and emergency response plan for a catastrophic event in the Delta

Although the DRMS risk analysis focuses on the Delta levees and the effects of flooding, the Delta Vision initiative directly considers the needs of a wide variety of resources and activities within the Delta and Suisun Marsh and beyond.

A key principle is to build the Delta Vision initiative around existing Delta planning, technical, and scientific efforts and avoid creating redundant organizational structures. In this way, DRMS will become a major source of scientific and technical information on the Delta and Suisun Marsh levees. Before the Delta Vision initiative, DRMS had already considered and taken on many of the same goals, activities, and functions as the Delta Vision initiative relating to levees, but focused on the development and presentation of technical information. The Delta Vision initiative will build on the technical information developed from the DRMS effort. The Delta Vision initiative will use many work groups that will work closely with, and preferably include, subject matter experts from ongoing Delta evaluations, such as the DRMS project.

A key component of Delta Vision is a Governor-appointed independent Blue Ribbon Task Force that is responsible for recommending future policies and actions to achieve a sustainable Delta. The process includes a diverse Stakeholder Coordination Group and broad public outreach to evaluate different Delta visions and management scenarios. The Task Force will submit a Delta Vision Report by the end of 2008 as well as a Delta Strategic Plan. A recommendation for conveyance is expected to be included in the plan. A cabinet-level Delta Vision Committee will submit the Delta Strategic Plan to the Governor and Legislature by December 31, 2008. More detail on the Delta Vision initiative can be found on its web site: http://www.deltavision.ca.gov/.

1.5.2 Bay-Delta Conservation Plan

The BDCP is a Natural Community Conservation Planning effort to address water operations and facilities in the legal Delta. The BDCP focuses primarily on aquatic ecosystems and natural communities, but may also cover adjacent riparian and floodplain natural communities. Among other things, the plan will:

- Provide for conservation and management of covered species
- Preserve, restore, and enhance aquatic, riparian, and associated terrestrial habitats
- Provide clear expectations and regulatory assurances for the water operations and facilities

The results from DRMS will provide levee risk information to inform the BDCP process. BDCP will work on a conservation strategy through late 2008. The final BDCP is expected to be completed in October 2009. More information on BDCP can be found on its web site: http://www.resources.ca.gov/bdcp/.

1.5.3 CALFED End of Stage 1

CALFED is preparing an assessment of performance towards objectives during Stage 1 (first 7 years of implementation) and the likelihood the program will meet its objectives in the future. Levees play a major role in the landscape of the Delta and how the CALFED program is implemented in the future. CALFED will use the results of DRMS to inform its planning process. More information on CALFED program planning can be found on the CALFED Bay-Delta Program web site: http://calwater.ca.gov/index.aspx.

1.5.4 Other Initiatives

The results of DRMS could prove useful to other initiatives in the region, including:

- The Delta Regional Ecosystem Restoration Implementation Plan, which is under the direction of the California Department of Fish and Game
- The Habitat Management, Preservation, and Restoration Plan for Suisun Marsh (Suisun Marsh Plan), which is currently being prepared by the Suisun Marsh Charter agencies
- Planning activities by state and federal agencies and local entities (for example, the Delta Islands and Levees Feasibility Study, which is being undertaken by the U.S. Army Corps of Engineers)
- Other new initiatives

1.6 REPORT ORGANIZATION

After this introduction, this report contains the following sections that collectively describe the risk to Delta and Suisun Marsh levees:

- **Section 2** provides an introduction to and a general description of the building blocks and scenarios.
- **Sections 3 through 17** present the results of the evaluations of the building blocks.
- **Section 18** presents the results of the evaluation of the scenarios.
- **Section 19** discusses the overall results and observations.
- **Section 20** describes the assumptions and limitations of the analysis.
- **Section 21** provides the references consulted in preparing the report.

Figures

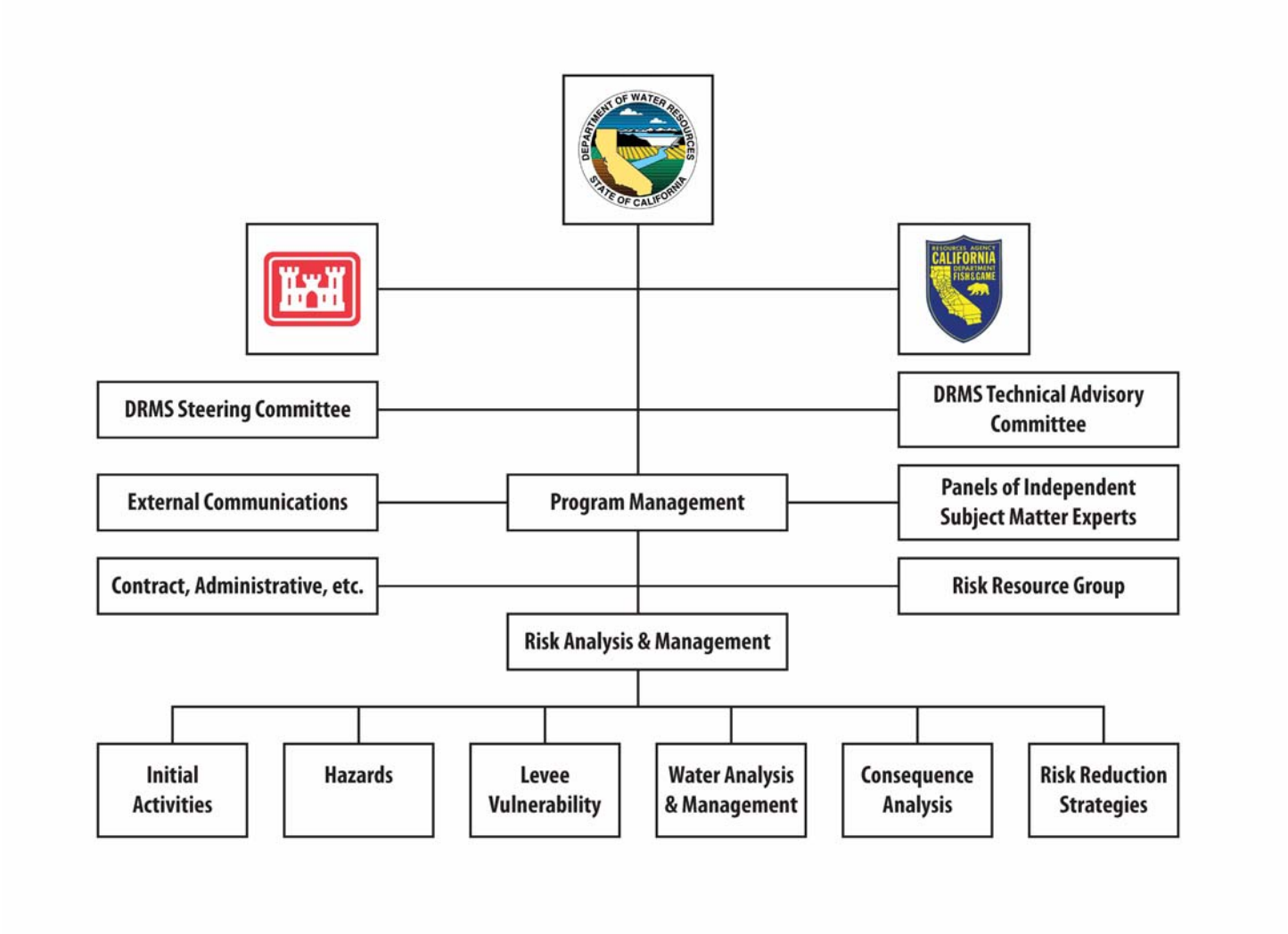

Figure 1-1 Program Functional Organization